PRESCRIPTIVE VS. PERFORMANCE BASED COOK-OFF FIRE TESTING

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ABSTRACT

In the fire safety community, the trend is toward implementing performance-based standards in place of existing prescriptive ones. Prescriptive standards can be difficult to adapt to changing design methods, materials, and application situations of systems that ultimately must perform well in unwanted fire situations. In general, this trend has produced positive results and is embraced by the fire protection community. The question arises as to whether this approach could be used to advantage in cook-off testing.

Prescribed fuel fire cook-off tests have been instigated because of historical incidents that led to extensive damage to structures and loss of life. They are designed to evaluate the propensity for a violent response. The prescribed protocol has several advantages: it can be defined in terms of controllable parameters (wind speed, fuel type, pool size, etc.); and it may be conservative for a particular scenario. However, fires are inherently variable and prescribed tests are not necessarily representative of a particular accident scenario. Moreover, prescribed protocols are not necessarily adaptable and may not be conservative.

We also consider performance-based testing. This requires more knowledge and thought regarding not only the fire environment, but the behavior of the munitions themselves. Sandia uses a performance based approach in assuring the safe behavior of systems of interest that contain energetic materials. Sandia also conducts prescriptive fire testing for the IAEA, NRC and the DOT. Here we comment on the strengths and weakness of both approaches and suggest a path forward should it be desirable to pursue a performance based cook-off standard.

INTRODUCTION

The goal of this paper is to discuss the role of testing & evaluation (T&E) as a means of demonstrating that requirements are being met. The motivation for this paper comes from the discussions concerning fast cook-off, both with the Department of Defense (DoD) research community and most recently with the DoD regulatory community regarding possible changes to STANAG4240. The authors, from the Department of Energy (DOE) laboratories, have seen the role of testing change significantly with the introduction of high performance computing combined with modeling and simulation (M&S) over the last 10 years. This combination is also becoming more prevalent within the DoD, particularly in shock physics, but has not yet penetrated to demonstrating cook-off requirements.

In order to describe the changes that occur with an integrated T&E/M&S program, some terms need definitions, for example, requirements. The real requirement for a set of munitions is the performance of the real systems in the real environment. While a motherhood statement on the surface, it in fact covers two important aspects to the problem – the system response and the environment in which the system is supposed to respond in. It is extremely important to recognize that both the system and the environment are important to meeting requirements.

Figure 1 shows a simplified graph of how both system performance and environmental loads show up. Obviously, for munitions, there are multiple environments, such as normal transportation/storage, abnormal accident, and hostile utilization environments and these environments may include thermal, mechanical, electrical, electromagnetic, etc. elements. Similarly, there are multiple performance specifications for munitions, and these depend on environment. For this paper, the discussion is limited to fast cook-off environments and hazard classification (HC) and insensitive munitions (IM) requirements.

For simplicity of discussion, we will limit the system performance discussion to Hazard Division 1.1 vs Division 1.3 although the discussion can be generalized as required.

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14. ABSTRACT
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15. SUBJECT TERMS

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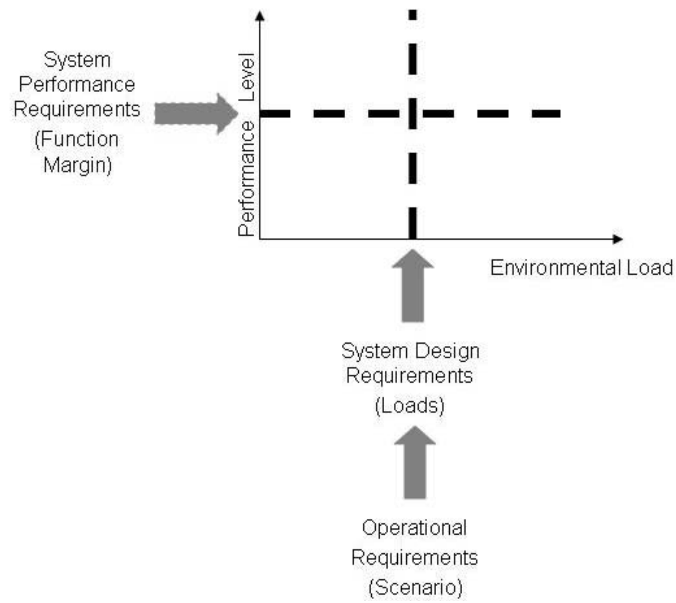

Fig. 1: Typical System Requirements Include Both System Performance Metrics and Requirements That the Performance Be Met Under Environmental Loads

One criterion in classification as Hazard Division 1.3 or lower (a system performance margin) is a 50 ft fragmentation distance in a fast cook-off environment. That is, no metallic fragments of 150 g (0.33 lb) or larger can be thrown a distance of 15 m (50 ft) or more. Hence, in Figure 1 a test that results in a measured result in the lower right quadrant is typically considered a successful demonstration of having met system requirements.

It is generally accepted that system response is a strong function of the load; thus the emphasis on carefully prescribing the load in terms of its controlling parameters, i.e. parameters such as fuel type, fire size, duration and location of the test target within the fire. This notion, while correct, is incomplete. In reality, the munitions under test and the fire are coupled and together behave as a system that drives itself toward some final outcome. In other words, the munitions are not simply responding to a fire input – rather the munitions and the fire are responding together to a much bigger set of controlling parameters. This bigger set of controlling parameters includes the characteristics of the local environment, the fire, and the configuration of the munitions - or the scenario.

In the final analysis, the scenario determines the outcome of the test, and is what must be prescribed. Such a prescription, until recently, would have been impossible as it requires detailed knowledge of both the fire environment and the munitions in real events. The available data and correlations developed from cook-off tests were sparse and only marginally applicable to any new test item. Even less quantifiable information was available from actual events. Typical understanding of a fire was that it could be a radiating black body at 1000°C in certain situations and the understanding of munitions was that worst case occurs when heating uniformly in a heavily confined configuration. However, with the advent of massively parallel computing capability and the accompanying software, it becomes possible to conduct high fidelity computational simulations and develop a more complete understanding of real-world cook-off events, which in turn leads to designing a proper test for any given set of munitions. The process of combining test data and computation to take scenarios to a final result is termed performance based testing.

In what follows, a procedure for conducting performance-based testing is put forth. The underlying issues in formulating a prescriptive test are discussed both from the point of view of the environment and from the item under test. It is shown how a performance based test overcomes these shortcomings. In the performance based process, a full understanding of the thermal response of the system is first required. Vulnerabilities to heating need to be understood, followed by selection of scenarios that lead to such heating. This in turn requires a full understanding of the fire environment. The underlying tool for developing this required understanding of both the munitions response and the fire environment is the Phenomena Identification and Ranking Table (PIRT) which establishes the gaps in needed models, test data, and computational capabilities. The process of modeling and testing is iterative requiring multiple PIRT passes as unknown unknowns are acquired and resolved. It is recognized that such an elaborate undertaking is not always warranted. However, it is pointed out that a single pass is essentially prescribing a test and is in fact the prescriptive based test approach. The subsequent passes which constitute the performance based approach allow for continuous improvement.

DESCRIBING THE ENVIRONMENT (SEPARATE FROM SYSTEM DESIGN)

When an environment specification is set independent of the system design, the test is usually a prescriptive test. For example, the Insensitive Munitions (IM) specification for fast cook-off, gives a prescriptive test in STANAG 4240* [1]. Paragraph 12 of STANAG 4240 states that:

> "The fuel fire tests are designed only to simulate the <u>most intense heating</u> conditions likely to be created in a hydrocarbon fuel fire. <u>They do not, however, simulate a particular in-service or accident scenario</u>." (emphasis added)

Interestingly, the Hazard Classification (HC) specification for fast cook-off testing at first glance appears to take a different tack. Instead of declaring a prescriptive, conservative ("most intense") heating scenario, the controlling document (TB-700-2 [2]) states:

> "The rate of heating should be <u>credible in relation to what might occur in an accident during transportation</u>, but it is not necessary to reproduce precisely all the conditions of a realistic fire. Suitable methods include a bonfire using brushwood, a wood fire using a lattice of wooden laths, a liquid fuel fire, a propane burner and a brazier." (emphasis added)

This seems to imply a performance-based specification, at least in terms of developing a "credible" fire environment. However, in practice, the two (IM and HC) specifications overlap. In fact, the IM document (STANAG 4240) says that the procedures "may also be used for Hazard Classification (HC) as required by STANAG 4123." This last document (STANAG 4123 [3]) then brings us full circle; for the US, its implementation is via TB-700-2, the HC document.

The approach of creating a standardized test that is used independent of the munitions being testing has a long tradition in testing. This basic approach has been used for decades, not only in DoD for munitions, but for other hardware. DOE used it for decades for testing its own hardware and the approach is used extensively in the building industry.

One of the important outcomes of such testing is consistency and another is low per-unit test cost. Large data bases have been developed showing the relative hardware performance against the test standard. The authors have noted across multiple agencies, for multiple applications, the discussions within the communities often have a distinct character. On one hand, there is often the admission that they cannot use the test data for any real situation because it does not represent any real situation. On the other hand, these data bases are extremely valuable because they are the only metric the community has for relatively assessing hardware performance. Across many communities, the latter point is felt so strongly that the community cannot conceive of ever doing anything differently because of the huge investment in this approach. There is a positive feedback mechanism at work – the more investment is made, the more reluctant people become to moving to a different approach.

Another self-propagating advantage of the prescriptive testing approach is low per-unit test costs. Once testing becomes standardized, there is little or no need to introduce new hardware and personnel can become efficient in the test method. This results in the lowest possible per-unit test cost for the development organization. Just as important, when the developing organization does its planning, it has a known testing path forward and can appropriately budget for the testing required.

On the other hand, there are some fundamental costs paid by continuing with this approach. Examples include the logic used to abstract an infinite accident scenario space to a finite number of tests is essentially static, independent of both weapon and platform changes, and the propagation of a false sense of security based on using a 'conservative load.' Documentation throughout the engineering community through the 1960's is so bad, that often times, the original logic used to abstract an infinite accident space to a finite number of tests is no longer accessible. It is easy to understand in a world where steel & aluminum are the primary materials used for platform construction, why a liquid hydrocarbon fire standard is chosen. However, as more and more platforms acquire more and more fuel from their composite structures, how is it that this change is fundamentally reflected in the test standards?

Perhaps the most pernicious problem with standardized testing that is independent of system performance is the concept of "conservative." Everyone agrees that for safety testing, that the test should be conservative. However, there is a difference between measuring a conservative system response, providing a conservative system load, and using a conservative scenario. As noted in the introduction, the real requirement is the performance of the real

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* The details of STANAG 4240, and the specifics around changes to the environment to permit propane testing are not relevant to this discussion.

system in the real environment. When tests are standardized independent of the system design, the result of the test cannot be a conservative demonstration of the system response.

Only in a very simplistic case can an ‘overtest’ result in a conservative response. Take a simple mechanical spring analogy for example. If a system has a single, one-degree-of-freedom response mode, then an overtest, e.g., the application of a load beyond what is expected in the environment will result in a conservative response of that spring. However, if there are multiple modes, for example, multiple springs, then the same overtest load cannot be said to be conservative because the partitioning of the energy between response modes that may have different susceptibilities to failure. Such testing does not result in a conservative design. It is simply a design that has been tested to the wrong requirements. Since munitions contain multiple response modes, a standardized test cannot possibly be considered to result in a conservative response. Hence the common overheard conversation that the test results are important in a relative sense, because they cannot be applied to real world situations with any confidence.

If a standardized test does not result in a conservative measure of the design, then it can either represent a conservative system load or a conservative scenario, or more often than not, neither. Early in the authors careers it was commonly thought that putting a weapon a meter above a fully engulfing liquid hydrocarbon pool fire would result in a conservative system load, i.e., that would be the hottest place in a fire. Testing throughout the 1990’s showed that this was not in fact the case. All pool fires, or jet flames for that matter, have a fuel vapor core that is significantly cooler than the turbulent flame brush. Perhaps not surprisingly, the fire is hottest where the fuel and air are burning most vigorously, which in a turbulent diffusion flame, is near the stoichiometric surface. For heavy hydrocarbon fuels, this is where relatively larger amounts of air are entrained, i.e., near the edge of the fire.

The use of the word conservative relative to a scenario is usually thought of as meaning of “low probability.” If quantifiable, and used within the context of probabilistic risk assessment methodologies, it has meaning. Otherwise, it is very often misunderstood to mean a scenario resulting in a conservative load.

SYSTEM PERFORMANCE SPECIFICATION

A complete system performance specification suffers because the system response modes are often not known. In fact, one could say, this lack of knowledge is the very reason for doing the prescribed test. However, we point out that the single prescribed test uncovers only one mode. Furthermore, the current test strategy with its go/no-go results give no insight into physics behind system performance. This results in a guarantee of testing for eternity as test data cannot be extrapolated to new designs. A proposed approach is the PIRT process which seeks to identify the important physics.

As an example, the PIRT process was used in a workshop held at the May 2008 JANNAF meeting. The workshop was set up to address the issue of the technical problems associated with cook-off of large rocket motors in fire environments. Forty-seven individuals, representing all branches of the US Department of Defense, Department of Energy, industry, academia and knowledgeable consultants participated in the workshop. The first step of the process was the specification of a credible scenario. Here we chose to investigate the scenario of an accident involving a large rocket motor during over-the-road transport. Physical phenomena associated with the accident event, the resulting fire, and the potential responses of the motor were identified by participants during a facilitated brain-storming session. The individual phenomena were then ranked by the group with respect to their perceived importance to the final outcome of interest – the throwing of fragments from the motor. The adequacy of experimental data and models to describe these phenomena were also ranked by meeting participants. The end result of the workshop was a prioritized list or table (the PIRT) of important physical phenomena for which there inadequate data and/or models to allow for prediction of the cook-off response. It was hoped that this exercise and the PIRT would be useful as a guide to prioritizing future research in the field. The workshop report was recently published as an unlimited release document. [4]

COMBINING T&E/M&S

Using a combination of testing & evaluation and modeling & simulation is nothing more than using the scientific method. A physics-based numerical/computational model is nothing more than the codification of theory. A simulation based on the numerical/computational model, or code as it is often called, is nothing more than a hypothesis. Testing takes on its usual role – truth is always established empirically. Thus combining T&E and M&S is the application of the scientific method to product testing.

Combining T&E/M&S does not change the purpose of testing: that is to build up a body of evidence that supports a decision that the hardware in question meets its requirements. What does change when combining M&S with T&E is the methodology, the quality of the body of evidence, and the costs. The methodology is iterative. First simulations of

the proposed experiments are run to evaluate the evidence that will be obtained by running the experiment. Specifically, the simulations will evaluate whether the test will optimally produce the body of evidence desired. All aspects of the test design can be optimized with in the uncertainty of the simulation predictions. Specifically checked is whether the instrumentation will remain in range and whether the output from that instrumentation will confirm the desired results.

The resulting test will not only provide the body of evidence that confirms the hardware, but can also be used to validate the model. By validate we mean establish the uncertainty in the prediction of the model. To accomplish the latter, it is necessary to include extra diagnostics to measure the uncertainty in the boundary conditions that are not normally needed for pure standardized tests. The test can be thought of in the scientific sense of a search for the unknown unknown not contained within the theory. If the test result is contained within the uncertainty of the theoretical prediction, then the test (with the extra diagnostics) can be used to reduce the bands of prediction uncertainty.

In this regard, M&S and T&E methods are synergistic. T&E can be thought of as the whole truth, partially exposed, while M&S can be thought of as a partial truth, wholly exposed. T&E is limited primarily by diagnostics that can extract useful physics insight into the test, while M&S is primarily limited by the amount of physics that can be contained within the model and still solved. T&E's primary strength is the physics content within the test while M&S strength is in the diagnostics that can be used to probe the physics within the model. For developing the evidence base for hardware qualification (i.e., it meets requirements), both M&S and T&E elements are aided by application of statistical mathematics to appropriately combine uncertainties into quantitative metrics defining the relative confidence one has due to the inherent uncertainties in the combined methodology.

The combined approach is necessary to address two of the shortfalls found in prescriptive testing, which is how to incorporate real scenarios and how to incorporate system response. Since abnormal or safety environments are unbounded, it is not possible by test alone to address how the environment will challenge the system. Through M&S it is possible to run any specific scenario of concern and address the relative difference in the thermal loads on the system. In this way, after acceptance, a means exists such that "what if" studies can be done to address scenarios that were not considered in the design of the prescriptive test. Further, with M&S, it is possible to assess system performance margins, not just go/no go acceptance criteria, as will be developed in the next section.

Of course, all this added benefit, comes at a price. In the short run, the costs are in fact higher but in the long run they are expected to be much lower. For a single development program, the cost of demonstrating that requirements are being met will more than double by a combined T&E and M&S approach. This point is easily seen in that T&E personnel & equipment costs are fundamentally different than M&S personnel & equipment costs. In addition to the T&E costs, which are not reduced but increased, one needs trained computational personnel and high performance computers. To lead order, the cost of M&S is on the same order as T&E when all hardware costs are taken into account. Further, as noted above, T&E costs increase due to increased instrumentation required to validate M&S results.

If the per-unit testing cost is higher, how is it possible for the combined T&E/M&S approach to result in lower overall costs? The answer lies in the fact that demonstrating that a product meets requirements is only part of the design/development cycle, and through the combined approach, the whole cycle cost, over time, can be decreased significantly. This point is not intuitively obvious and needs explanation with examples.

As noted above the combined T&E/M&S approach is nothing more than the application of the scientific method and, over the long haul, nothing has proven more successful at driving technology forward than the application of the scientific method. A well understood example exists within the automotive manufacturing community. Arguably, the US had the most experience in manufacturing of complex systems such as automobiles of anybody in the world prior to the 1980's. After all, the US had pioneered assembly line manufacturing. And yet within a decade or two, the entire process was revolutionalized by the Japanese application of Deming's methods. Simply put, the method was basically to instrument the manufacturing process to reduce the number of products not passing requirements. By understanding the process, it could be improved and over a number of cycles, result in a lower overall cost with a significantly improved product quality. In essence, testing took on an additional role. Instead of just testing the product, and throwing away defective product, testing of the process improved the manufacturing process.

This is in essence what the authors are proposing will happen to the design process. Through a combination of T&E/M&S with an expanded role for M&S to include testing (validation) of the physics models (M&S) on which design is based, the design process will become more productive and result in lower costs. As a specific example, take the formulation of new propellants for large rocket motors. This was the subject of the PIRT exercise explained in system performance specification section. By the time large rocket motors are tested, a failure to make Class 1.3 can be very expensive. If the existing product testing T&E community could be utilized not just to determine pass/fail at the end

stage of development, but can be leveraged to understand the design process at an early stage, then considerable savings would result as well as a vastly improved range of products. The authors believe this is the design equivalent of the manufacturing advance made in the 1980-2000 time frame.

DESCRIBING THE ENVIRONMENT & SYSTEM DESIGN ITERATIVELY

To revolutionize the design process with a combined T&E/M&S approach, it is necessary to incorporate the design into testing, i.e., to move beyond prescriptive tests to performance based testing. As stated above, the real requirement is the performance of the real system in the real environment. Thus, the two attributes of system performance and the environmental loads shown in Figure 1 cannot be separated. However, the combination presents a subtle “chicken and egg” type difficulty. One cannot know system performance until there is a system design, and one cannot design a system to perform appropriately until the load is understood.

The current approach within the DOE community for abnormal accident environments for which there are weapon safety performance requirements is to adopt an iterative approach, which has been termed representative, conservative, accident scenario (RCAS). For a given accident scenario, the twin adjectives, representative and conservative apply to the environment and system response respectively. Scenarios are chosen to represent a broad class of conditions in which the weapon may find itself. Not surprisingly, large hydrocarbon pool fires represent one class of accidents. However, the second adjective, conservative, changes the nature of the test from prescriptive to performance based. Conservative means to use unknowable load details within the representative scenario to drive a system design implementation vulnerability. In this way, the design and the environment are coupled. By necessity, as the design evolves, the test will evolve as well.

For this process to end up being cost effective, the validation part, i.e., establishing the uncertainty in the numerical simulation tools, must occur early enough that the simulation tools can be utilized early in the design cycle. It is through the simulation tool application in design as well as development testing, that the design process becomes “instrumented” in the manner that was described for manufacturing processes. Rather than simply conducting go/no-go testing and throwing parts away, the T&E community can become more effective during the design process, resulting in cost savings.

THE CHALLENGE FOR DOD FAST COOK-OFF TESTING

DOE has been able to adopt the performance approach because of the limited types of munitions in its purview and the potential high consequences involved. Does the same apply to the DoD with its multitude of munitions? While prescriptive testing is cheap(est) on a per test basis, the fact that progress is glacial means that overall it is more expensive than a combined T&E and M&S approach. So what is the challenge?

The primary challenge to the DoD community to implement this approach for fast cook-off testing is, in the authors’ opinion, primarily one of being able to physically describe the system response mode. In other words, what mechanisms, or series of mechanisms within the system results in fragments being thrown over 50 ft when heated in a fire. All the other major challenges are being worked in parallel through other programs. If DoD wants a combined approach, then it must invest in understanding the physics/chemistry of system response. DDESB must be the driver for this understanding. We encourage the DDESB to continue to strongly support the R&D community to move this understanding forward.

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This work was performed at

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REFERENCES

[1] NATO Standardization Agreement (STANAG) 4240, Liquid Fuel/External Fire, Munition Test Procedures (Edition 2) April, 2003.
[2] Technical Bulletin (TB) 700-2, Naval Sea Systems Command Instruction (NAVSEAINST) 8020.8B, Technical Order (TO) 11A-1-47, Defense Logistics Agency Regulations (DLAR) 8220.1, "Department of Defense Ammunition and Explosives Hazard Classification Procedures, January 5, 1998.
[3] NATO Standardization Agreement (STANAG) 4123, Determination of the Classification of Military Ammunition and Explosives (Edition 3), May 1995.
[4] Erikson, W.W., Nicolette, V.F., Tieszen, S.R., Renlund, A.M., Minier, L.M.G. and Atwood, A.I. "Cookoff Scaling Workshop Report" JANNAF 43rd CS, 31st APS, and 25th PSHS Joint Meeting, La Jolla, CA, Dec. 2009.

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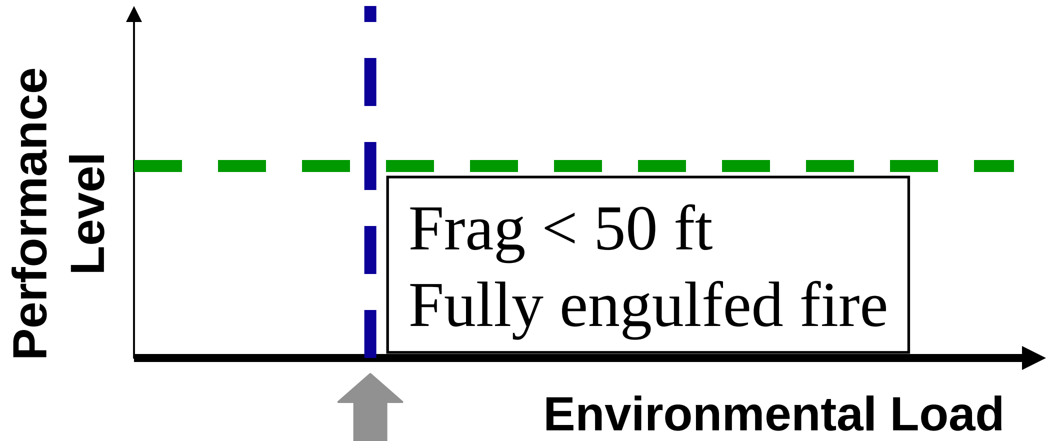
Outline

- Testing & Meeting Requirements
- Describing the Environment Separate from Design
- System Performance Specifications
- Combining Test/Evaluation With Modeling/Simulation
- Describing the Environment & System Design Iteratively
- Conclusions
- Acknowledgments

Requirements Definition

System Performance Requirements (Function Margin)



System Design Requirements (Loads)

Operational Requirements (Scenario)

- **The real requirement is the performance of the system in the real environment.**

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Describing The Environment Separately from System Design

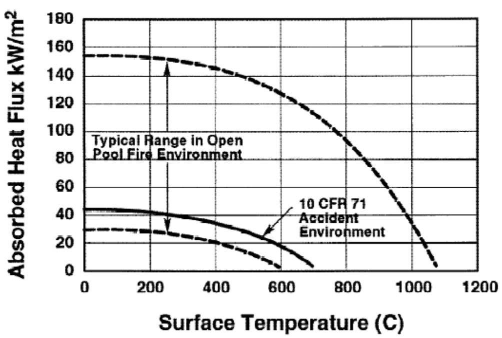
The Event:

Prescriptive Test

Performance Based Process

Fire Specification

E 2230 – 02



Is this conservative?
Is this representative?

Fire Physics

	Basic Concept	Integral Physics over space and time	Spatially Resolved/ Time Integral Physics	Space and Time Resolved Physics
Parameters	Temperature Heat Flux	Plume Height Air Entrainment Puffing Frequency Recession Rate	Combustion Turbulence/Mixing Soot Radiation Virtual Instrumentation	Droplets Suppression Coupling with Objects Soot Modeling
Models	Radiating Source	Correlations Zone Models	Time Averaged Field Model (RANS) VULCAN	Large Eddy Field Model (Time Resolved) FUEGO

Knowledge of the environment determines the approach.

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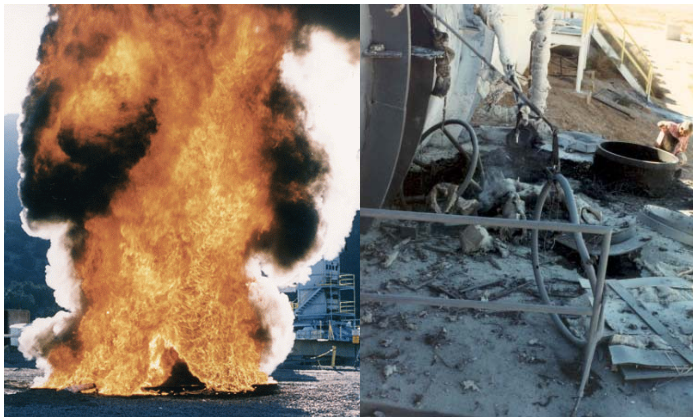
System Performance Specification

Prior Experience
(environments / responses)



Phenomena Identification & Ranking Table
(quantify your prior experience)

No.	Main Category	Sub-category	Phenomena	importance	material properties	small-scale tests	med-scale tests	full-scale tests	model adequacy	model validation	scale-up confidence
#18	Fuel Fire	Heat Load	Convection	2.67	2.40	2.25	2.20	2.17	2.20	2.33	2.25
#51	Pre-Ignition Propellant Decomposition	Chemistry	Pyrolysis	1.71	2.40	2.00	2.00	2.00	1.60	1.40	1.40
#61	Pre-Ignition Damage Evolution	Macro-cracks	Bondline Cracks	2.50	1.75	1.25	1.50	1.33	1.50	1.25	1.25
#76	Propellant Combustion & Dynamics	Burning Rates	Pressure Dependency	2.78	3.00	3.00	2.40	1.80	2.40	2.40	2.40

Prescriptive Test Approach

•Poorly understood phenomena are isolated.
•Use specified test to control the poorly understood phenomena (e.g. declare a specification and be consistent)
•Hope is for consistent tests to allow comparison (but are they Representative? Conservative?)
•Defined procedure allows *a priori* estimation of test program costs; cheaper for single program

or

Performance Based Process

•Poorly understood phenomena are flagged for further investigation
•Representative scenario for system of interest
•Combined experimental & modeling
- Series of experiments and models highlighting specific physics
- Builds up toward qualification test & simulations

•Simulation-aided design allows long-term cost savings (costs not reduced for a single system)

Broader foundation of Experience results from performance based process.

Combining Test/Evaluation With Modeling and Simulation

- **Using a combination of testing & evaluation and modeling & simulation is nothing more than using the scientific method.**
- **A physics-based numerical/computational model is nothing more than the codification of theory.**
- **A simulation based on the numerical/computational model, or code as it is often called, is nothing more than a hypothesis.**
- **Testing takes on its usual role – truth is always established empirically.**

Combining T&E and M&S is the application of the scientific method to product testing.

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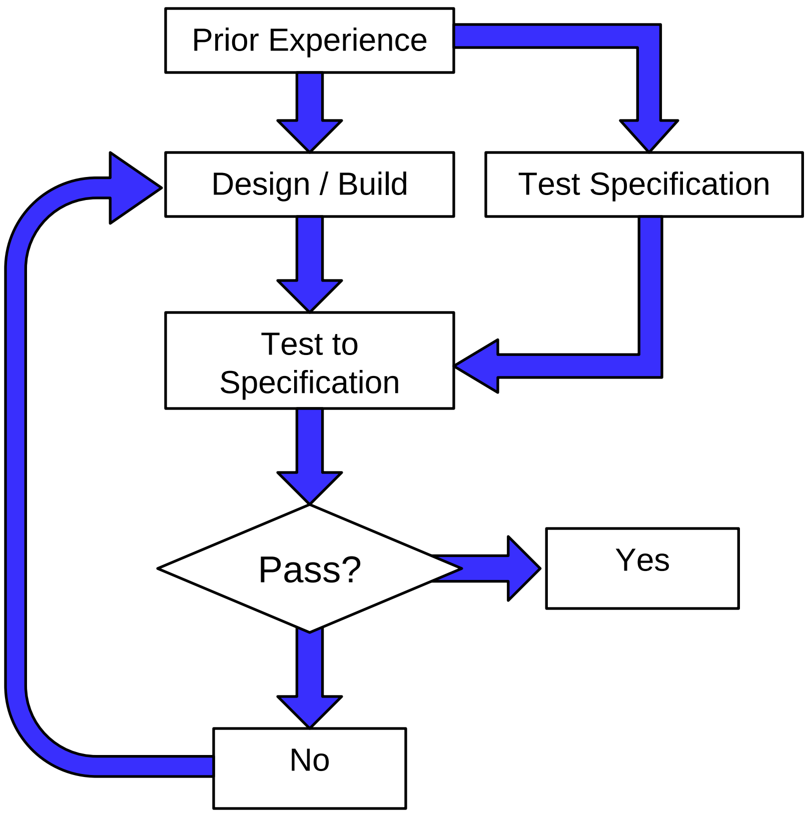
Describing The Environment & System Design Iteratively

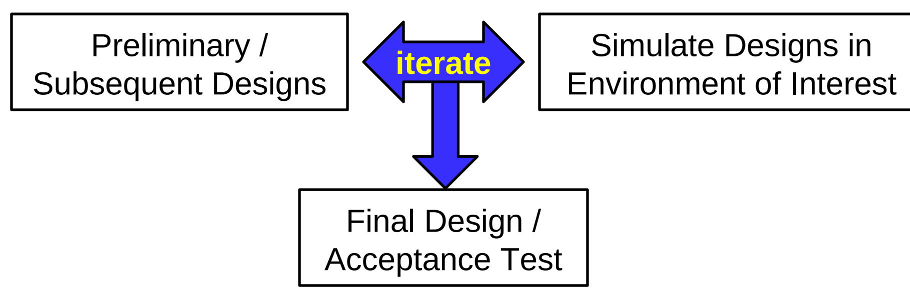
Prescriptive Paradigm



Performance-Based Paradigm

Test & Experimentation		Modeling & Simulation
• Discovery Experiments	⟷	• Model Development
• Calibration Experiments	⟷	• Model Parameterization
• Validation Experiments	⟷	• Prediction / Comparison
• Qualification	⟷	• Accreditation
		• Examine Use Cases

Design Cycle



If models have been fully established one time, subsequent design cycle becomes very efficient:

Conclusions

	Thermal Load	Response	Challenge
Prescriptive	Duration Diameter	Uniformly heated Fully engulfed	Is this conservative? Is this representative?
Performance Based	RCAS Configuration	• Detailed Heat Transfer Paths • Decomposition Chemistry of all materials • Post Ignition behavior	• Where does all this information come from? • Are the models as being used valid?

- **Prescriptive challenges can be difficult if not impossible to address adequately.**
- **The broader testing community is already addressing performance based challenges for the thermal load.**
- **Understanding munitions response is the critical path to move to performance-based process.**

We encourage the DDESB to continue to strongly support the R&D community to enable the performance-based process.

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